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PHOSPHORUS AND NITROGEN LOADING OF LAKE VALENCIA

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ABSTRACT

The phosphorus and nitrogen content of streams and canals entering Lake Valencia was determined at monthly intervals betweem 1977 and 1981. Estimates were also made over the same interval of phosphorus and nitrogen loading from bulk precipitation and from groundwater. For 1977-78, total annual phosphorus loading averaged 2.43 g/m²/yr and nitrogen loading averaged11.2 g/m²/yr. In 1979-81 after some additional water diversions to Lake Valencia, the total phosphorus loading averaged 3.31 g/m²/yr and total nitrogen loading averaged 10.3·g/m²/yr. Without sewage, but with other present-day nutrient sources, the phosphorus loading of the lake would only be about 20 % of its present level. The natural background phosphorus loading for the lake (i.e., no inhabitants in the watershed), as judged from the chemistry of the Rio Limon, is probably less than one-tenth of the present-day phosphorus loading. Sewage presently dominates the loading of the lake, and has changed the ratio of nitrogen to phosphorus, drastically increasing the relative amount of phosphorus. Taking into account the size and mean depth of the lake. Lake Valencia is one of the most heavily loaded large lakes in the world. It is estimated that the phytoplankton biomass of the lake has been increased approximately ten fold from its natural level by addition of sewage to the lake.

CONTENIDO DE FOSFORO Y NITROGENO EN AGUAS QUE DESCARGAN EN EL LAGO DE VALENCIA

RESUMEN

Se determinó mensualmente el contenido de fósforo y nitrógeno de las aguas de ríos y canales que desaguan en el Lago de Valencia, entre los años 1977-81. Se estimó también, durante el mismo período, el aporte de fósforo y nitrógeno al lago, por parte de la precipitación total y aguas subterráneas. Para el período 1977-78, la entrada total anual de fósforo promedió 2,43 g/m²/año y de nitrógeno, 11,2 g/m²/año. Entre 1979 y 1981, después de que se desviaran aguas adicionales al Lago de Venezuela, la entrada promedio de fósforo total fue de 3,31 g/m²/año y de nitrógeno total fue de 10,3 g/m²/año. La carga de fósforo al lago, sin la entrada de aguas servidas, pero con otras fuentes actuales de nutrientes, representa sólo aproximadamente el 20 % de su nivel del contenido actual. La carga de fondo natural de fósforo para el lago, esto es, sin habitantes en la cuenca, estimada de las características químicas del Río Limón, probablemente representa menos de una décima de la entrada de fósforo de hoy día. Las aguas servidas, o aguas negras, dominan la carga de nitrógeno y fósforo al lago y han cambiado la proporción de estos elementos allí, incrementando drásticamente la cantidad relativa de fósforo. Tomando en cuenta el tamaño y la profundidad promedio del lago, el Lago de Valencia es uno de los más cargados en estos compuestos, en el mundo. Se estima que la biomasa de fitoplancton del lago ha sido incrementada aproximadamente diez veces por encima de lo que sería su nivel natural, debido a la entrada de aguas servidas al lago.

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INTRODUCTION

Lake Valencia receives constant nutrient additions from domestic and industrial sources. It is likely that the lake has always been productive,[4] but the present large additions of nutrients must contribute substantially to algal standing stock, which is very high. The extreme dominance of blue-green algae[5] and large blooms of buoyant scum-forming algae that now typify the lake are symptomatic of eutrophication.

The nutrient budgets of Lake Valencia have not yet been quantified except in a very preliminary way.[3] As part of a comprehensive study of the lake, we have estimated phosphorus and nitrogen input between 1977 and 1981. We present here the data on loading from different sources, quantify the total loading, and show the extent of annual and seasonal variation in loading.

METHODS

Data on surface and groundwater flows are taken from the water budget information of Lewis.[2] Data on nutrient loading from bulk precipitation are from Lewis.[1] For surface runoff, concentrations of soluble reactive, dissolved organic, and particulate phosphorus and nitrogen were measured monthly between 1977 and 1981. Water was collected from each flowing stream or canal around the perimeter of the lake. At the same time, the discharge from each of the streams or canals was measured.[2] After all samples were collected, they were mixed by volumes proportionate to the discharge of their sources at the time of collection. Thus if Caño Central contributed 75 % of the total of all measured discharges, it would make up 75 % of the mixed sample. All samples were agitated well prior to sub-sampling in order to keep particulates in suspension.

The mixed stream sample, consisting of volume-weighted contributions from all sources, was analyzed as follows. The sample was filtered through a pre-weighed Whatman GF/C glass fiber paper (effective pore size, ca 2.0 µm). The filter was re-weighed after drying to constant weight at 60° C. This yielded an estimate of total particulates. The filter was digested in a heated Kjeldahl flask with K_2SO_4 in concentrated sulphuric acid until the solution was clear. The solution was then diluted to 500 ml with distilled water and analyzed for orthophosphate by the ascorbic acid/molybdate method of Murphy and Riley.[7] The method was repeatedly standardized with U.S. Bureau of Standards orchard leaves. Digestion efficiency was very near 100 %.

The filtrate was analyzed for orthophosphate by the method of Murphy and Riley.[7] The dissolved organic P was determined by ultraviolet oxidation of a portion of the filtrate in

TABLE I

CHARACTERISTICS OF SURFACE DISCHARGE INTO LAKE VALENCIA BASED ON MONTHLY DATA FOR 5 YEARS. CONCENTRATIONS ARE GIVEN AS UNWEIGHTED MEANS

	1977	*1978*	*1979*	*1980*	*1981*	*R. Limon*	*Ground Water*
Measured Discharge (l/sec)	4264	6630	10494	11348	14324	–	–
Concentrations (μg/l)							
Soluble reactive P	2501	2728	2300	2856	2059	40	59
Dissolved organic P	654	364	< 50	< 50	< 50	< 1	< 5
Particulate P	2258	2015	1467	1129	803	11	–
Total P	5313	5270	3860	4116	2892	51	59
NO_3-N	590	288	149	114	199	557	232
NO_2-N	96	52	16	26	67	0	18
NH_4-N	20225	10207	5498	5724	3194	37	56
Dissolved organic N	1608	1062	1581	143	< 50	222	630
Particulate N	4843	6949	4250	3732	2956	37	–
Total N	27363	18559	11486	9741	6417	853	936
Particulate Characteristics							
Concentration, mg/l	241	388	395	153	209	278	10
% P	0.91	0.75	0.53	0.74	0.43	0.10	–
% N	1.98	1.75	1.47	2.49	1.51	0.36	–
% C	30.3	23.4	20.0	25.8	16.8	6.7	–

the presence of oxygen.[6] After digestion, the sample was analyzed for orthophosphate. Increase in orthophosphate concentration after digestion was attributed to dissolved organic P.

Particulate nitrogen and carbon were determined with a Carlo-Erba elemental analyzer. Methods for analysis of the dissolved nitrogen fractions were as given by Lewis.[1]

Wellwater samples and samples from the undeveloped portion of the Rio Limon watershed were also analyzed. Wellwaters were taken from four wells at Macapo, Guigue, Guacara, and Punta Larga in November 1981 and analyzed by the same methods as streamwater. A Rio Limon sample was taken in May 1982 and analyzed by the same methods. Total P in this analysis was compared with a series of 56 total P measurements on Rio Limon between November 1973 and August 1975 (F.H. Weibezahn, unpublished). Total P of the larger series compared well with the single 1982 measurement (43 μg/l mean for the series, 51 μg/l for May 1982). The May 1982 data are used here because complete nitrogen fractionation was available for this sample.

RESULTS

Table I summarizes the concentrations of dissolved constituents and the characteristics of particulate material in the measured surface discharge to Lake Valencia. The years 1977 and 1978 are different in many respects from 1979 through 1981. In general, concentrations of dissolved constituents were lower in the last three years of the study than in the first two, while total measured discharge to the lake was almost double. These differences are explained by additional diversions to Lake Valencia at the beginning of 1979. The additional nutrients brought by the newly diverted water were more than compensated by additional volume of flow, thus resulting in a decline of concentrations for dissolved nutrients. In addition, there were considerable differences in the amount of rainfall in different years, adding to the variance in concentrations. For example, rainfall was highest in 1981,[2] resulting in reduction of average concentrations for most fractions and increase in volume of measured flow to the lake that year. Within each year, there is a dilution of nutrients during the rainy season.

Total phosphorus concentrations in the surface water entering Lake Valencia are very high on all occasions. The bulk of total phosphorus is accounted for by soluble reactive phosphorus and particulate phosphorus; only a small fraction is accounted for by dissolved organic phosphorus. For nitrogen, ammonia is the dominant fraction, as would be expected in water dominated by sewage. Particulate nitrogen also makes a significant contribution, however.

For particulates, the percentage carbon indicates that about half of the total weight can be accounted for by particulate organic matter and the other half by mineral or soil particles. Although the total particulate load is relatively high, the percentage of nitrogen and phosphorus in the particulates is not especially great.

TABLE II

TOTAL P AND N LOADING FROM MEASURED SURFACE RUNOFF AND N AND P LOADING DUE TO PUMPED EFFLUENT, ALL EXPRESSED AS MG/M²/DAY FOR LAKE

	Phosphorus		*Nitrogen*	
Year	*Total Loading*	*Base Loading*	*Total Loading*	*Base Loading*
1977	4.6	3.9	26.8	13.0
1978	6.7	4.0	19.4	16.1
1979	8.2	7.9	25.7	21.4
1980	9.1	7.3	20.8	20.7
1981	8.0	7.3	19.2	13.3

Table I also shows the concentrations of nitrogen and phosphorus fractions and characteristics of particulates in the Rio Limon. Except for nitrate nitrogen, most of the concentrations are far below the concentrations in total surface runoff to the lake. The same is true of groundwater, which is also summarized in Table I. Information on particulates for groundwater is omitted. The particulate fraction is not considered to be transported to the lake because of its inability to penetrate the aquifers that feed the lake.

Table II summarizes the total nitrogen and phosphorus loading for measured surface runoff. The table also shows the base loading, which is obtained by computing the loading during the months of the dry season when there is no rain and thus no contribution other than pumped sewage, and extrapolating this over the entire year. The difference between the total loading and the base loading is thus the contribution which occurs strictly as a result of the augmentation of overland transport of nutrients by runoff associated with the rainy season. In 1977 and 1978, the base loading is roughly 2/3 of the total loading, although there are variations between the two years in the exact percentage depending on the amount of rainfall and the rainfall distribution over the year. Nonetheless, it is clear that, for 1977 and 1978, the base loading accounts for well over half of the total loading from measured surface runoff. This tendency is even greater in the years 1979 through 1981, when the contribution from base loading exceeded 3/4 of the total in most instances.

Table III summarizes the total loading for phosphorus and nitrogen from all sources in 1977-78 and 1979-81. The first component is total surface runoff, which is not identical to measured surface runoff shown in Table II. The water budget study showed that a certain amount of runoff, equal to 28 % of the measured discharge into the lake, enters the lake by unmeasured pathways such as unchanneled runoff, large pulses of runoff associated with short storms, etc. Since this water is not sewage, its nutrient concentration was estimated by subtracting the base loading from the total loading in Table II and computing the concentration of the resulting nutrients diluted over the fraction of the discharge in excess of the pumped flow. This increment added to the measured surface loading gives the total loading from surface runoff. Bulk precipitation loading derives from Lewis[1] and groundwater loading derives from the data in Table I and the estimate of groundwater flow into the lake obtained in the water budget study.[2]

Two types of backgrounds are also approximated in Table III. The non-sewage background is the loading which would be expected if none of the sewage entered the lake, assuming land use remains the same. Thus this approximation would include all diffuse nutrient sources and all natural nutrient sources but not sewage effluents. The method for calculating this was as follows. The loading of nitrogen and phosphorus during the dry season was assumed to represent the point sources only, as other sources have no means of entering the lake at this time. By extrapolating the dry season loading rates across the entire year and subtracting from the total loading, one obtains a residual which is an approximation of the background loading without sewage. This is the basis of the figures given in Table III. In addition, Table III shows a natural background. This is obtained by assuming that the concentrations of nutrients observed in the Rio Limon represent the concentrations of nutrients that would be typical of all runoff into the lake if the watershed were completely uninhabited and supported a natural vegetative cover. This is obviously only a very rough approximation because the Rio Limon may not be the best possible representation of the entire watershed in its natural state, but the order of magnitude is probably correct.

TABLE III

PHOSPHORUS AND NITROGEN LOADING FOR LAKE VALENCIA, AS G/M²/YR.

	Phosphorus			
	Total Surface Runoff	*Bulk Precipitation*	*Groundwater*	*All Sources*
1977-1978	2.23	0.17	0.03	2.43
1979-1981	3.11	0.17	0.03	3.31
Non-Sewage Background	0.45	0.17	0.03	0.60
Natural Background	0.03	0.17	0.03	0.23

	Nitrogen			
	Total Surface Runoff	*Bulk Precipitation*	*Groundwater*	*All Sources*
1977-1978	9.30	0.75	1.17	11.2
1979-1981	8.34	0.75	1.17	10.3
Non-Sewage Background	2.00	0.75	1.17	3.92
Natural Background	0.44	0.75	1.17	2.36

DISCUSSION

In view of the population size of the Lake Valencia watershed and the absence of advanced phosphorus treatment facilities or sewage diversion projects, the loading of the lake with nutrients is well within the expected range. The total loading from the land surface of 3.11 g/m²/yr total phosphorus in the years 1979-81, representing the sewage contributions of the entire watershed and non-point sources, corresponds to 3.96 kg/ /ha/yr over the 2,760 km² of watershed. According to the literature summary by Reckhow and Simpson,[8] this amount is between the ranges expected for high agricultural yield and urban yield, reflecting the mixed urban/agricultural nature of the Lake Valencia watershed. The background export coefficient without the sewage component is 0.57 kg/ha/yr total phosphorus. This lies within the midrange of agricultural values from the literature summary by Reckow and Simpson.[8] The population of the watershed over the period of study averaged about 1,700,000 persons. This corresponds to a per capita phosphorus yield of 0.55 kilograms per year for the sewage component of loading (i.e., after subtraction of the non-sewage background). Once again, this value per capita is in the midrange of literature values. Since the sewage component dominates, the per capita phosphorus contribution to the lake in the form of sewage obtained from this study can be used to

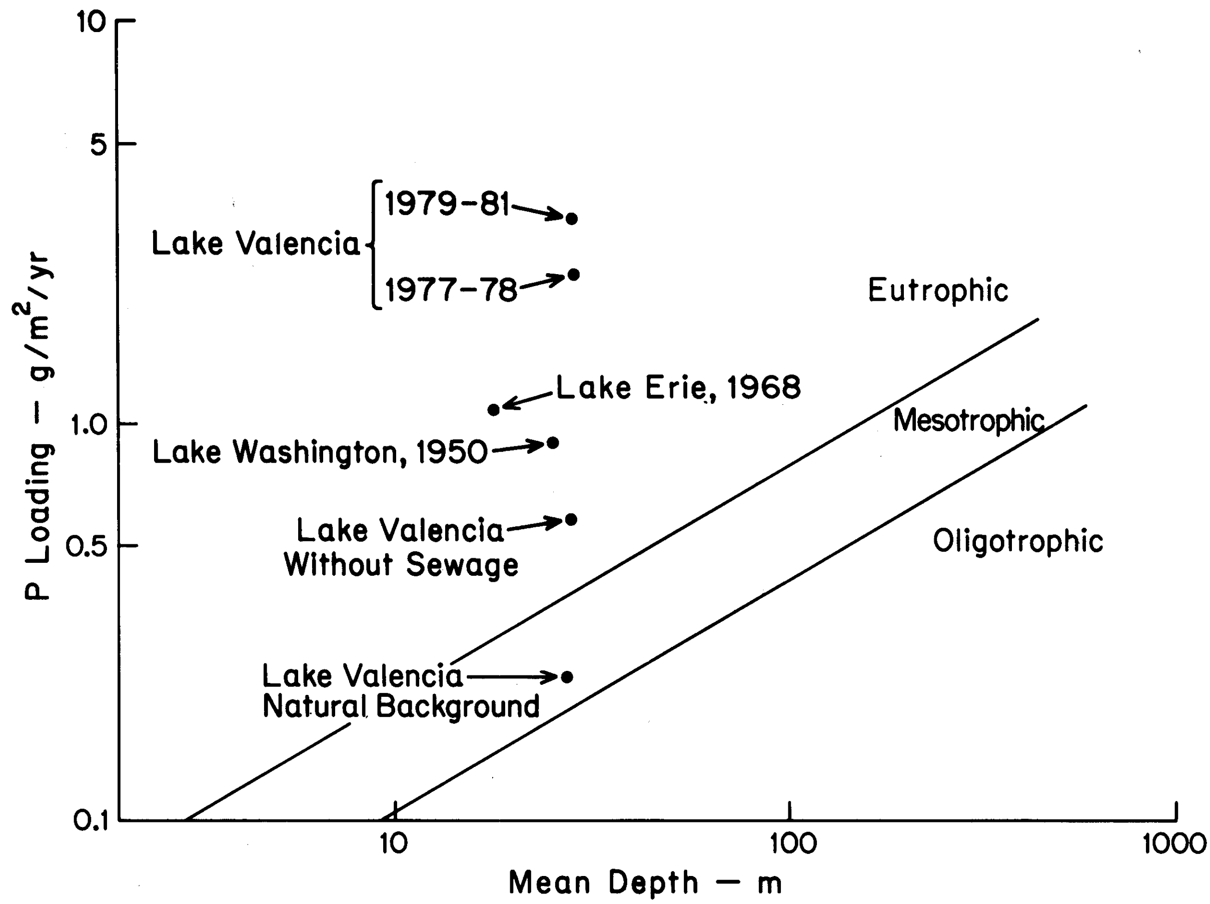

Figure 1. Total phosphorus loading for Lake Valencia between 1977 and 1981 compared with expected loading without sewage and expected loading under natural (uninhabited) conditions. The position of two well-known temperature eutrophic lakes prior to treatment is also shown.

approximate the impact of further population increases in the Lake Valencia watershed. The figure could also be used to approximate improvements to be expected in the trophic status or total phosphorus loading of the lake as a result of various kinds of point source treatment procedures.

The addition of large amounts of sewage to Lake Valencia has drastically changed the loading ratio of nitrogen to phosphorus. For the natural background approximation, the atomic ratio for loading is 22.8 N:P. The requirement for phytoplankton protoplasm is about 16 N:P. Thus the natural background loading of Lake Valencia is much more likely to have favored phosphorus limitation of algal growth, although the exact ratios of available phosphorus to available nitrogen from the historical past cannot be reconstructed because of the differential mobilization of these two elements in lakes. In the non-sewage background for present day Lake Valencia, the ratio is 14.4 N:P. Although this represents a slight increase in the relative supply of nitrogen over the natural background, it is not an extreme departure from the expected supply ratio of N to P from natural landscapes. The ratio for the sewage component for the years 1979-81, however, is 6.73 N:P. This is expected because sewage typically shows a low ratio of N to P (expected ratios for municipal sewage generally range between 6 and 14 [9]). The extreme change in ratio of supply of the two critical elements and phosphorus essentially guarantees that nitrogen will be the limiting element and that dominance of blue-green algae over other types of algae will be strongly encouraged. Very dense populations of scum-forming blue-greens that are now characteristic of the lake can thus probably be traced in large part not only to the strong enrichment of the lake but also to the change in the ratio of nitrogen to phosphorus.

Figure 1 shows the phosphorus loading of Lake Valencia on the widely used Vollenweider diagram for lake trophic status.[10] Lake Valencia, which is hypereutrophic, is one of the most heavily loaded of large lakes worldwide. The diagram indicates that, in its natural state, Lake Valencia would probably fall within the mesotrophic category. On the basis of Figure 1, the difference in total phytoplankton biomass between the present-day lake and the lake in its natural condition is approximately a factor of ten, with corresponding changes in the transparency of the lake.

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